according to the Compton equation should produce this effect between 80° and 90°. Apparently little change in the energy of the tertiary radiation from carbon (short wave-length limit .211 Å) due to the tungsten $K\alpha$-doublet takes place in wave-lengths as long as .2308 Å in this scattering range.

From the results of the experiments with a silver radiator and tungsten primary rays, we would expect the observed effects to occur in any experiment in which the scattered radiation was examined at various angles, with a screen whose critical absorption wave-length had the proper value, and provided that the wave-lengths of the tertiary radiation differed sufficiently from that of the primary.

[1] NATIONAL RESEARCH FELLOW.
[2] *Proc. Nat. Acad. Sci.*, **9**, 413, 419; **10**, 41; et seq.
[3] Wagner, *Phys. Z.*, **21**, 621 (1920); **23**, 503 (1922).
[4] Ross, Proc. Am. Phys. Soc., *Physic. Rev.*, **22**, 525 (1923).
[5] A. H. Compton, *Physic. Rev.*, **21**, 483 (1923).

THE SERIES SPECTRA OF THE STRIPPED BORON ATOM (BIII)

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Communicated March 27, 1924

In a preceding article[1] we have brought forward evidence that in "hot spark" spectra the strongest lines generally correspond to atoms from which the valence electrons have all been stripped off, so that the resulting spectrum is hydrogen-like, i.e., is due to one single electron moving between the series of levels characteristic of a simple nucleus-electron system.

For such a nucleus-electron system the Bohr theory in its elementary form[2] which dealt only with circular orbits, i.e., with variations in azimuthal quantum numbers, the radial being always zero, yielded at once the result that the energies corresponding to a given quantum state, e.g., quantum number 1, increased in the ratio 1,4, 9, 16, etc., as the nuclear charged increased in the ratio 1, 2, 3, 4, etc. This meant physically that the frequencies corresponding to jumps from infinity to an orbit of given quantum number, technically called term-values, when divided by the square of the nuclear charge should come out a constant; otherwise stated that the constant term in the Rydberg formula should become N, 4N, 9N, 16N.

After the introduction by Sommerfeld of radial in addition to Bohr's azimuthal quantum numbers the foregoing conclusions were obviously

still applicable to the series of *circular* orbits corresponding to a given azimuthal quantum number and the varying nuclear charges 1, 2, 3, 4, etc.

These conclusions have recently been shown by Bohr,[3] Paschen,[4] and Fowler[5] to check with considerable accuracy with the experimental energy levels obtained through the study of the optical spectra produced by the stripped atom of sodium (Na_I), Magnesium (Mg_{II}) and Aluminum (Al_{III}) as the following f term-values (energy levels) when divided through by 9 for Al, 4 for Mg, and 1 for sodium show. The four 4_4 circular orbits (the large 4 meaning total and the subscript azimuthal quantum numbers) obtained from elementary Bohr theory and the observed fundamental series in Na_I, Mg_{II}, Al_{III} give for the foregoing ratios.

Theory 6858.44, Na_I 6860.4, Mg_{II} 6866.8, Al_{III} 6871.28.

The agreement between the elementary Bohr theory and experiment for the 6_6, 5_5 orbits with all these metals is even better, and that for the 3_3 almost as good.

Now the most conspicuous of Bohr's very recent contributions to the physics of the atom has consisted in the systematic analysis of the departures from the foregoing elementary theory which are to be expected from the *assumption* of the penetration (especially because of orbits of high ellipticity) of the radiating electron into the inner regions of the atom where it is no longer shielded from the nucleus by the inner shell, and where, therefore, the effective value of the nuclear charge is suddenly increased and with it the numerical value of the total energy of the orbit,[6] and hence the numerical value of the frequency corresponding to that orbit. These term values, divided by n^2, for the highly elliptical orbit 3_1, as shown herewith, bring out sharply the departures in the case of this orbit from the value given by the elementary theory and the progression of this departure.

Elementary theory 12192.78, Al_{III} 25494.89, Mg_{II} 30316.9, Na_I 41449.00.

It will be seen that all these term-values (energy levels) are systematically larger than that given by the elementary theory.

By applying the foregoing considerations to the computation of the spectrum to be expected from the stripped atom of boron, B_{III}, it should be possible to predict with the greatest accuracy the spectral lines due to jumps between the circular orbits of the larger radii. Thus, the jump between the circular orbits 5_5 and 4_4 ($4f - 5f'$) should give a line of frequency

$$\nu = 9N_B(1/4^2 - 1/5^2) = 9 \times 109732.(1/16 - 1/25) = 22221 \text{ or } \lambda = 4500.3 \quad (1)$$

In the early stages of this work the boron spectrum had been obtained for short wave-lengths inside the vacuum spectrometer and simultaneously

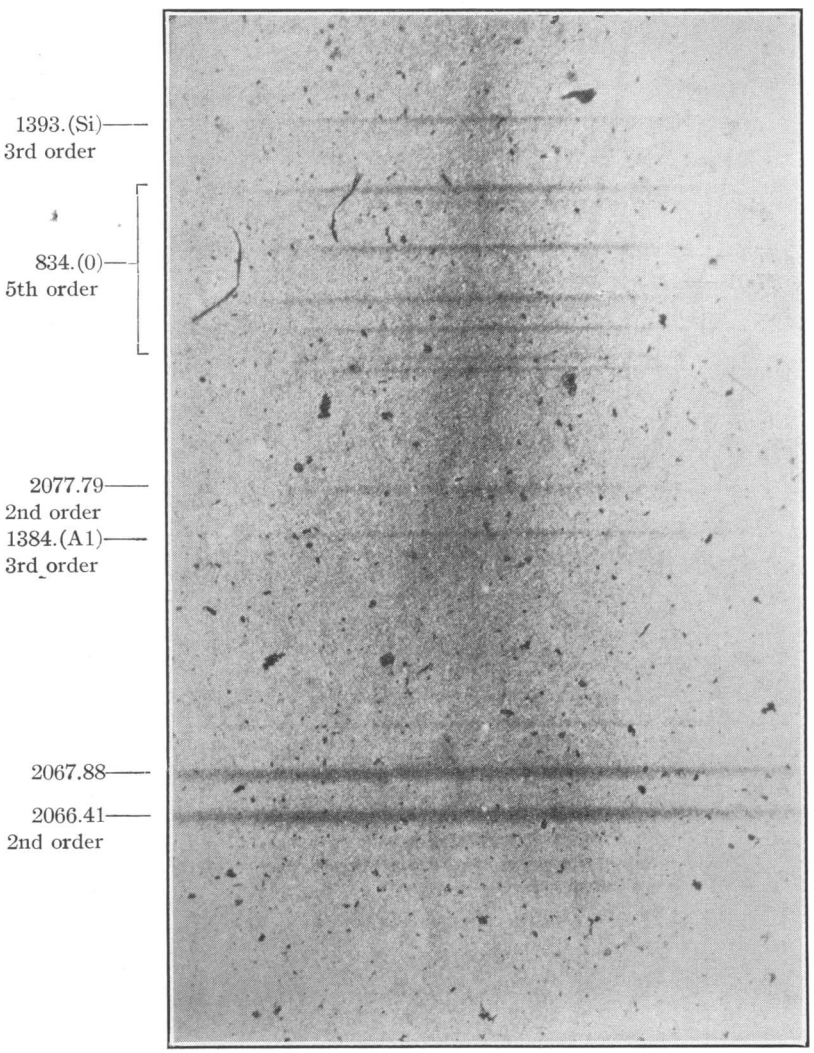
1393.(Si)
3rd order
834.(0)
5th order
2077.79
2nd order
1384.(A1)
3rd order
2067.88
2066.41
2nd order

FIGURE 1

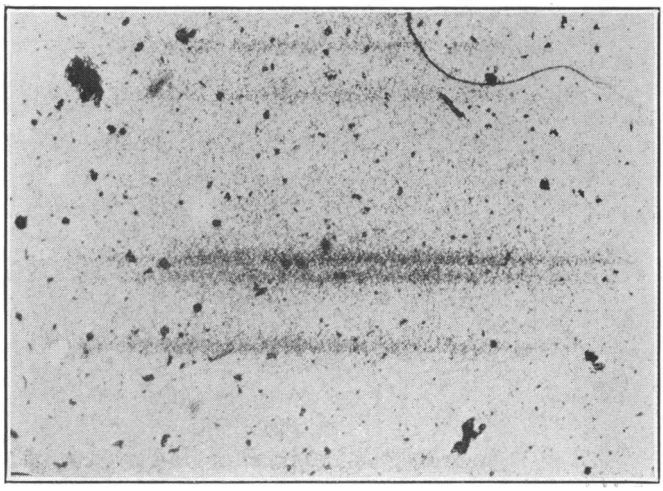

FIGURE 2

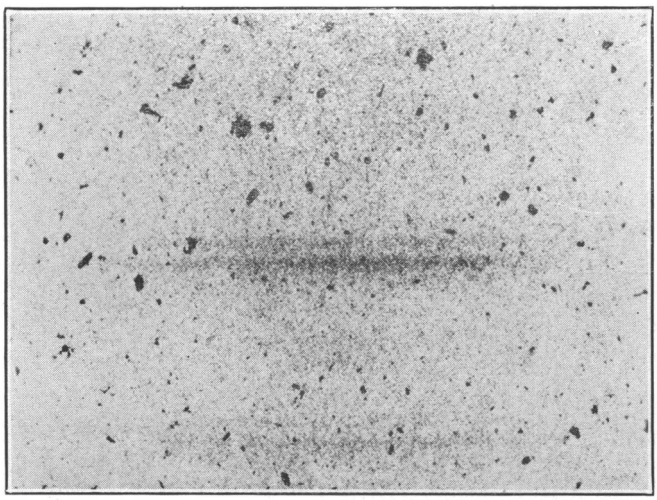

FIGURE 3

for long wave-lengths outside, the light coming through a quartz spectrograph. A study of the plates taken with the aid of this quartz spectrograph revealed at once a hitherto unidentified line at $\lambda = 4499.0$. *To an accuracy of one part in three thousand this is in exactly the spot predicted by the elementary theory.*

Again, the jump between the circular orbits 4_4 and 3_3 ($3d - 4f$) should be given by the foregoing formula when the 5 and 4 are replaced by 4 and 3, respectively. The carrying through of this computation yields $\lambda = 2083$. But since the departure shown by Paschen and Fowler from the elementary theory becomes greater the smaller the orbits (presumably because the electrons of the k shell begin to exert influences appropriate to their actual position outside of instead of in the nucleus) it should be more correct to attempt to predict the position of the boron line here being sought by simply dividing through by $3^2 = 9$ the wave-length of the corresponding lithium line at $\lambda = 18697$ A. This gives the predicted position at 2077.4 A.

Plate No. 1 was taken for the sake of studying with high resolution hot-spark vacuum spectra from electrodes containing boron the wave-length region about $\lambda = 4150$ A. which region should contain the second order of the predicted line at 2077, the existence of which had never been brought to light by any preceding observers. *This plate reveals the line sought and gives it a wave-length of 2077.79, within about one part in 5000 of the predicted position.*

The next jump to be expected in B_{III} is that from the 3_3 to the 2_2 orbit ($2p - 3d$). But in the alkali type of spectra there are always two p terms, p_1 and p_2 giving rise to a doublet $2p_1 - 3d$ and $2p_2 - 3d$, so that the line to be here expected is a close doublet. Its very approximate wave-lengths should be given by substituting 2 and 3 for the 4 and 5 of formula (1). This gives 729 A. But again the prediction should be more accurate by dividing the corresponding lithium doublet, which is at 6103 A, by 9. This gives 678 A, which is within about an angstrom of the strongest boron line below 1300 A. which we have already published in our "Extreme Ultra-violet Spectra,"[7] in which work there had been no indication that the line was a doublet. *In new studies on the structure of this line made with the use of a very narrow slit (.02 mm.) and with spectra of order from the third to the sixth the line was definitely revealed as a close doublet in all of the plates and orders studied.* Fig. 2 of the plate shows a photograph of this doublet in the sixth order. The average separation of the doublet as determined from measurements on several different plates and in four different orders is .15 A. correct to at least .01 A. The resolution here shown has so far as we know never been obtained in any preceding work in the extreme ultra-violet. The corresponding frequency separation is $\Delta\nu = 32.7$ cm.$^{-1}$.

There should of course also be a doublet of this separation caused by a jump to this same pair of levels p_1 and p_2 from the 3_1 orbit. This should be the first term of the sharp series of B_{III}, i.e. $(2p_1 - 3s)$ and $(2p_2 - 3s)$. A study with our high resolution of the fine structure of all the strong lines of boron below 2000 A.—there are but six of them—revealed but one other doublet, namely 758.47—758.68, which had the same frequency separation. *This definitely identifies, then the line, the wave-length of which we had previously published at 758.5 as the first term of the sharp series of* (B_{III}).

There should be one further jump giving rise to another doublet of this same frequency difference, namely, the jump from the p_1, p_2 pair of levels to the $2s$ orbit, and since this would be the first term of the principal series it should be the strongest existing (B_{III}) line. We had already located this strongest boron line at 2066.2 and 2064.2 and attributed it to the stripped boron atom[8] but had taken these wave-lengths and their separation from a preceding observer who had worked in air.

Making now a study under high resolution, in both first and second orders (see Fig. 1 of the plate for a very excellent reproduction of this doublet in the second order) we fixed these wave-lengths at 2066.41 and 2067.88, which corresponds to a frequency separation of 34.4. *This exhausts all the* B_{III} *lines which can be expected to appear in any strength, and all of them have been found where they should be and with the right separation for all the predicted doublets.*

The separation of the 677 doublet (32.7) is a trifle less than the much more accurately determined separation (34.4) of the $2s - 2p$ line. The difference is only 5% and may be accidental, since the estimated accuracy of .01 A. amounts in .15 A. to 7%, but it is interesting to note that a corresponding discrepancy was found for the same line in lithium and in this case given an interesting explanation by Fowler.[9]

Table I gives the complete results of our study with high resolution of the fine structure of all of the strong boron lines which we have brought to light, only two of these lines, the pairs at 2066 and at 2090, having been previously mentioned by other observers. It will be seen that the lines at 1826 and 2090 are both doublets, but with a frequency separation which definitely identifies them with B_I, since it is the same as that given by Fowler,[10] namely $\Delta\nu = 15.3$, for the B_I lines at 2497. The 1082 and the 1624 lines are revealed by our plates as complex lines, though the resolution was not sufficient to determine their true character. Hence only the mean wave-length is given in our table.

The term values given in the last column were determined from our measurements of the wave-lengths of these boron lines, starting with the $5f'$ level, which was computed from the elementary theory and then corrected by a study of the deviations from the elementary theory of the corresponding levels in Al_{III} and Li_I.

BORON

INT.	λI. A. VAC.	ν		Δν	B_{III}	TERM VALUES
3	677.01	147708.3	$2p_2 - 3d$	32.7	2s	305938±5
3	677.16	147675.6	$2p_1 - 3d$		3s	125736±5
2	758.47	131844.4	$2p_2 - 3s$	36.5	$2p_1$	257545±5
3	758.68	131807.9	$2p_1 - 3s$		$2p_2$	257579±5
2	1081.99	92423.2			3d	109870±5
6	1362.45	73397.2			4f	61742±5
7	1624.09	61579.1			5f′	39515±5
1	1825.87	54768.4	BI	16.2		
2	1826.41	54752.2	BI			
4	1842.78	54265.8				
10	2066.41	48393.1	$2s - 2p_1$	34.4		
10	2067.88	48358.7	$2s - 2p_2$			
3	2077.79	48128.1	3d − 4f			
3	2089.60	47856.0	BI	15.8		
3	2090.29	47840.2	BI			
2	4499.0	22227.2	4f − 5f′			

[1] Millikan and Bowen, *Physic. Rev.*, **23**, 1–31, 1924.

[2] *Phil. Mag.*, **26**, p. 1, 1913.

[3] Bohr, *Ann. Physik.*, **71**, 228, 1923.

[4] Paschen, *Ibid.*, **71**, 185, 1923.

[5] Fowler, *Proc. Roy. Soc.*, **103**, 427, 1923.

[6] Since Bohr takes the energy as zero at infinity a higher numerical value of the energy—itself negative—means of course a lower actual energy in the inverse sense of the atomic number.

[7] Millikan and Bowen, *Physic. Rev.*, **23**, 7, 1924.

[8] See page 32, *l. c.*

[9] Fowler, *Report on Series in Line-Spectra*, p. 98.

[10] *Ibid.*, p. 155.